Reverberation time regulations for stairwells and corridors – A pilot study for housing and schools in selected countries in Europe

Carrascal García, Teresa; Rasmussen, Birgit

Published in:
Conferencias y Comunicaciones del XI Congreso Iberoamericano de Acústica, X Congreso Ibérico de Acústica y 49º Congreso Español de Acústica

Publication date:
2018

Document Version
Accepted author manuscript, peer reviewed version

REVERBERATION TIME REGULATIONS FOR STAIRWELLS AND CORRIDORS – A PILOT STUDY FOR HOUSING AND SCHOOLS IN SELECTED COUNTRIES IN EUROPE

PACS: 43.55.-n

Carrascal García, Teresa[1]; Birgit Rassmusen[2]
[1] Eduardo Torroja Institute for Construction Science, IETcc – CSIC
C/ Serrano Galvache 4.
28002 Madrid, Spain
Tel: (+ 34) 91 32 04 40
E-Mail: tcarrascal@ietcc.csic.es
[2] Danish Building Research Institute (SBi), Aalborg University Copenhagen
A.C. Meyers Vænge 15
2450 Copenhagen. Denmark .
Tel: (+45) 9940 2364
E-Mail: bir@sbi.aau.dk

Keywords: Reverberation time, sound absorption, acoustic regulations, housing, schools, stairwells, corridors.

ABSTRACT

Noise in stairwells and corridors is often disturbing to people in the rooms and in adjoining rooms, especially in housing and in schools. For that reason, several European countries include reverberation time requirements in their acoustic regulations as a way to control noise in stairwells and other communal areas. However, acoustic requirements vary widely between countries and are missing in some countries.

This paper compares reverberation time and sound absorption requirements for stairwells and corridors for housing and schools in selected countries in Europe, and it includes up-to-date information on the applied limit values, frequency ranges, measurement standards and verification procedures.

1 INTRODUCTION

Corridors and stairwells are often regarded as secondary spaces when designing a building, but noise transmitted through them can be potentially annoying to the occupants of adjacent rooms, specially when there are doors opening to them. The most frequent approach to noise control in stairwells and corridors is to add an acoustic lining to the ceiling of these spaces. Thus, some European countries include either requirements for reverberation time or sound absorption area in their Building Codes.

There are several studies comparing different aspects of acoustic regulations in housing [1-4] and in schools [4-6], but none of them included stairwells and corridors. The idea to write this paper was initiated by the discussions during COST Action TU0901, see e.g. [3] and in the working group ISO/TC 43/SC 2/WG 29, while preparing an acoustic classification method for dwellings [8]. It was realized that some countries had such requirents for housing, while others never considered that. In the beginning of the work, the majority of countries were against a mandatory rule, so it became optional, but in the end most countries found such limits useful, and they became a mandatory part of a classification according to [8].

This paper shows a comparative study of room acoustic requirements (reverberation time or sound absorption) for stairwells and corridors in housing and schools for selected countries in Europe. The paper contains up-to-date limit values, frequency ranges, measurement standards and verification procedures. The measurement, rating and calculation standards applied are EN ISO 3382-2 [9], EN ISO11654 [10] and EN 12354-6 [11]. The countries and reference publications considered are: Belgium [12-13], Denmark [14], England [15-16], France [17-19], Italy [20-21], Norway [22-23], Portugal [24] and Spain [25-27].

2 Acoustic regulations

Concerning the the selected countries of this study, the room acoustic criteria found in regulations are either reverberation time or equivalent sound absorption area. In some countries, these rooms are not considered to be places for speech communication, and the focus of the regulations, where they exist, is to reduce the noise levels, so noise transmitted to adjoining rooms via the corridor/stairwell is reduced. In some other countries, stairwells and corridors are considered as places, which should also be comfortable for speech communication.

In this paper, a stairwell is defined as a passage through a building which contains a set of stairs. Some countries, like France and Spain limit requirements for stairwells to those which are not enclosed, e.g. when a stairwell is connected to a corridor.

A corridor is a passage into which rooms, e.g. classrooms or apartments open. In some countries, requirements for corridors are also applied to other communal spaces such as hallways and atria. The building regulations in England define a corridor as a "space for which the ratio of the longest to the shortest floor dimension is more than three" as opposed to entrance halls, but no other geometric distinction has been found in the rest of the regulations studied.

While reverberation time requirements seem to be optimum for the verification in-situ according to EN ISO 3382-2 [9], equivalent absorption area requirements are more convenient for designing the building. EN ISO 12354-6 [11] can be used for calculations, but some countries provide examples and lists of the absorption coefficients of common materials as guidelines to designers, see e.g. [15-16] and [27]. France has also an interesting procedure for the verification of the absorption area installed in situ described in [18], consisting of inspections, checking absorption materials installed and making calculations.

For both sets of requirements, reverberation time and absorption area, frequency ranges vary from country to country, in France and Belgium absorption area requirements are weighted, and product information must be rated according to EN ISO 11654 [10].

The sections 3 and 4 include tables with room acoustic regulations for stairwells and corridors in housing and schools. Standards are referred to using EN ISO references, although national references would include the national standardisation organisation, e.g. NF/EN ISO 11654 and NS/EN ISO 3382-2 as examples from France and Norway, respectively.

3 HOUSING – ROOM ACOUSTIC REGULATIONS FOR STAIRWELLS AND CORRIDORS

The regulatory requirements for room acoustic regulations for stairwells in housing are found in Table 1 and for corridors in Table 2 for the eight selected countries in Europe. For each country, the tables indicate the limits and details of importance for design and check of compliance with the limits.

Table 1: Housing – Room acoustic requirements for stairwells – Selected countries in Europe

Housing – Room acoustic requirements(1) for stairwells(2) – August 2018					
Status (1) / **Country**	Requirement	Fur-nished room	Freq. range [Hz]	Details of requirement/criterion	Comments
Belgium [12]	$A_w \geq 0.3 \cdot S_H$ S_H = walkable surface area, as seen in a plan view	–	250-4000	$A_w = \Sigma(\alpha_{w,i} \cdot S_i)$ Only surfaces with $\alpha_{w,i} > 0.05$ may be included in the summation	Frequency range defined in [10].
Denmark [14]	T ≤ 1.3 s	–	500-2000	T20 according to ISO 3382-2 Max. in each 1/1 octave band	
England [15]	$A_w \geq S \cdot \alpha_{w,ClassD}$ or $A_w \geq 0.5 \cdot S \cdot \alpha_{w,ClassE}$, S defined in [15]	–	250-4000	A_w resulting from applying Method A described in [15]	Method A in [15] consist of covering a certain surface, S, of the stairwell with a class C or D absorber acc. [10]. Frequency range defined in [10].
France [17]	$A \geq 0.25 \cdot S_{floor}$	+	250-4000	Min $A = S \cdot \alpha_w$; S is the surface of the absortive lining wiht α_w rated acc. to [10].	Does not apply to enclosed stairs and lifts. Frequency range defined in [10].
Italy [20]	None				
Norway [23]	T ≤ 1.0 s	+	500-4000	T20 according to ISO 3382-2 Max. in each 1/1 octave band	
Portugal [24]	None				
Spain [25]	None				
(1) Overview information only. Detailed requirements and conditions are found in the references. (2) Rooms unoccupied, unless other conditions indicated.					

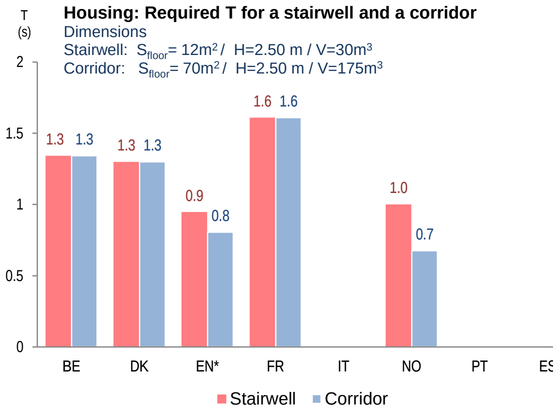
Table 2: Housing – Room acoustic requirements for corridors – Selected countries in Europe

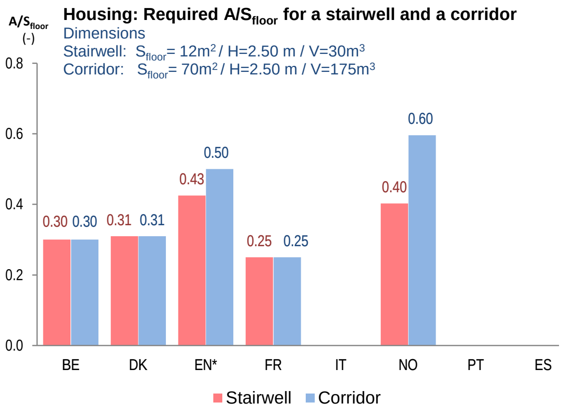
Housing – Room acoustic requirements(1) for corridors(2) – August 2018					
Status (1) / **Country**	Requirement	Fur-nished room	Freq. range [Hz]	Details of requirement/criterion	Comments
Belgium [12]	$A_w \geq 0.3 \cdot S_H$ S_H = walkable surface area, as seen in a plan view	–	250-4000	$A_w = \Sigma(\alpha_{w,i} \cdot S_i)$ Only surfaces with $\alpha_{w,i} > 0.05$ may be included in the summation	Frequency range defined in [10].
Denmark [14]	$T \leq 1.3$ s	–	500-2000	T20 according to ISO 3382-2 Max. in each 1/1 octave band	If corridors are applied for stay, $T \leq 0.9$ s is required, furnished room.
England [15]	$A \geq 0.2 \cdot V$ (m²) V= volume	–	250-4000		Alternative method A in [15] of covering a certain surfaces of a class C or D is also possible. Frequency range defined in [10].
France [17]	$A \geq 0.25 \cdot S_{floor}$	+	250-4000	Min $A = S \cdot \alpha_w$; S is the surface of the absortive lining; α_w from EN ISO 11654	Does not apply to external corridors, enclosed stairs and lifts. Frequency range defined in [10].
Italy [20]	None				
Norway [23]	$T \leq 0.27 \cdot h$ (s) h = room height	+	125-4000	T20 according to ISO 3382-2 Max. in each 1/1 octave band. For 125Hz, max. +40% accepted.	Additional criterion for α_m, cf. [23]
Portugal [24]	None				
Spain [25]	None				
(1) Overview information only. Detailed requirements and conditions are found in the references. (2) Rooms unoccupied, unless other conditions indicated.					

As seen from Tables 1 and 2, only Denmark and Norway have reverberation time requirements. Three countries do not have requirements, neither in stairwells nor in corridors in housing, that is the case of Italy, Portugal and Spain. The rest have equivalent sound absorption area requirements. Concerning the requirements for stairwells and corridors in each country, reverberation time limits in Norway are lower (stricter) in corridors than in stairwells. England also requires more sound absorption to corridors than to stairwells, whereas Belgium and France have the same requirements for equivalent absorption area for stairwells and for corridors in housing.

The variety of descriptors complicate comparisons between countries as frequency ranges are different and in most cases requirements depend on the geometry of the rooms, e.g volume or floor surface. In order to allow for comparison, Figure 1a shows the values of the reverberation time requiered to a corridor and a stairwell whose dimensions are stated in the graphs. The rooms correspond to a real housing block in Madrid. Figure 1b shows the ratio of the equivalent sound absorption area to the floor surface for the same stairwell and corridor. In the conversion between descriptors, the Sabine equation has been used and it has been assumed that the calculated sound absorption areas are single values, so Figures 1a and 1b show an approximate estimaton of which requirements are stricter.

From the Figures 1a and 1b, it can be seen that the reverberation time limits spread significantly for both spaces: from 1.6 s to 0.8-0.7 s. Norway requires a lower reverberation time and also a higher sound absorption area to floor surface ratio: 0.6, whereas the average ratio of A/S_{floor} in this example results in 0.34 for stairwells and 0.39 for corridors.





* Method A acc. Approved Document E. Resistance to sound has been applied. The reverberation time and A/S_{floor} were calculated for a minimum α_w of a class D absorber.

Important details about requirements, e.g. frequency ranges can be found in Tables 1 and 2.

Fig. 1a: Estimated reverberation time required for an example of a stairwell and a corridor in a housing block

Fig. 1b: Estimated A/S_{floor} ratio required for an example of a stairwell and a corridor in a housing block

4 SCHOOLS – ACOUSTIC REGULATIONS FOR STAIRWELLS AND CORRIDORS

The regulatory requirements for room acoustic regulations for stairwells in schools are found in Table 3 and for corridors in Table 4 for the selected eight countries in Europe. For each country, the table indicates the limits and details of importance for design and check of compliance with the limits.

Table 3: Schools – Room acoustic requirements for stairwells – Selected countries in Europe

Schools – Room acoustic requirements(1) for stairwells(2) – August 2018					
Status (1) / **Country**	Requirement	Fur-nished room	Freq. range [Hz]	Details of requirement/criterion(3)	Comments
Belgium [13]	$A_w \geq 0.4 \cdot S_H$ S_H = walkable surface area, as seen in a plan view	–	250-4000	$A_w = \Sigma(\alpha_{w,i} \cdot S_i)$ Only surfaces with $\alpha_{w,i} > 0.05$ may be included in the summation	Increased requirements $A_w \geq 0.5\ S_H$ only applicable to specific target groups, i.e. students with auditory or communicative disabilities Frequency range defined in [10].
Denmark [14]	T ≤ 1.3 s	–	500-2000	T20 according to ISO 3382-2 Max. in each 1/1 octave band	
England [15], [16]	$A_w \geq S \cdot \alpha_{w,ClassD}$ or $A_w \geq 0.5 \cdot S \cdot \alpha_{w,ClassE}$, S defined in [15]	–	250-4000	A_w resulting from applying Method A described in [15]	Method A in [15] consists of covering a certain surface, S, of the stairwell with a class C or D absorber acc. [10]. Frequency range defined in [10].
France(3) [17]	T ≤ 1.2 or $\leq 0.15 \cdot V^{1/3}$ (s) V= volume	+	500-2000	RT defined as the average of 500, 1000 and 2000 Hz. T20 according to ISO 3382-2	Regulations do not include stairwells explicitly. For this paper, they have been considered circulation spaces. Enclosed stairwells are excluded. Frequency range defined in [10].
Italy [20] [21]	None				
Norway [23]	T ≤ 0.8 s	+	500-4000	T20 according to ISO 3382-2 Max. in each 1/1 octave band	
Portugal [24]	None				
Spain [25]	$A \geq 0.2 \cdot V$ (m²)	–	500-2000	A defined as the average of 500, 1000 and 2000 Hz.	Enclosed stairwells are excluded.
(1) Overview information only. Detailed requirements and conditions are found in the references. (2) Rooms unoccupied, unless other conditions indicated. (3) Requirements for circulation spaces bigger than 250 m³. Depending on volume each requirement is applied. If rooms are smaller than 250 m³, then the absorption area must be greater than $0.50 \cdot S_{floor}$					

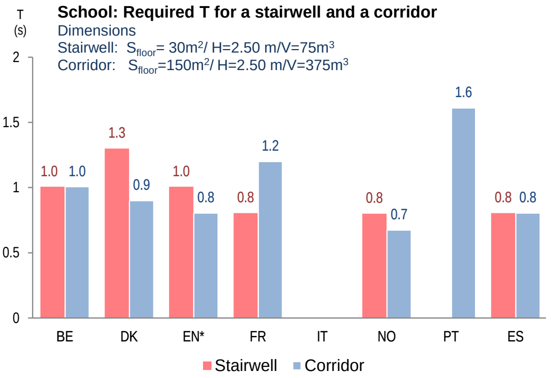
Table 4: Schools – Room acoustic requirements for corridors – Selected countries in Europe

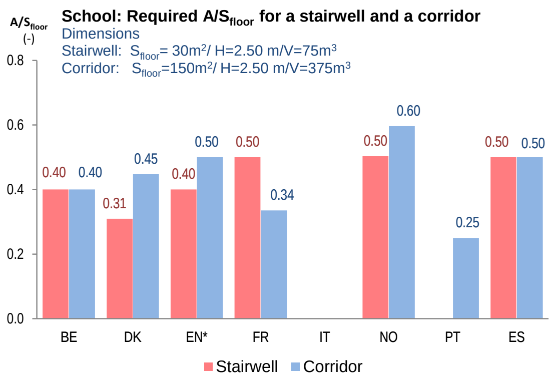
Schools – Room acoustic requirements(1) for corridors(2) – August 2018					
Status (1) / **Country**	Requirement Requirement	Fur-nished room(2)	Freq. range (Hz)	Details of requirement/criterion(3)	Comments
Belgium [13]	$A_w \geq 0.4 \cdot S_H$ S_H = walkable surface area, as seen in a plan view	–	250-4000	$A_w = \Sigma(\alpha_{w,i} \cdot S_i)$ Only surfaces with $\alpha_{w,i} > 0.05$ may be included in the summation	Increased requirements: $A_w \geq 0.5 \cdot S_H$ only applicable to specific target groups, i.e. students with auditory or communicative disabilities. Frequency range defined in [10].
Denmark [14]	$T \leq 0.9$ (s)	–	500-2000	T20 according to ISO 3382-2 Max. in each 1/1 octave band	If corridors are applied for group work, the limit is 0.4 s for 125-4000 Hz, furnished room.
England [15], [16]	$A \geq 0.2 \cdot V$ (m^2) V= volume	–	250-4000	Min. in each 1/1 octave band	Alternative Method A [15] of covering a certain surfaces of a class C or D is also possible. Frequency range defined in [10].
France(3) [17]	$T \leq 1.2$ or $\leq 0.15 \cdot V^{1/3}$ (s) (4) V= volume	+	500-2000	RT defined as the average of 500, 1000 and 2000 Hz. T20 according to ISO 3382-2	Recommendations for schools for children under 6 are given in [19]
Italy [20] [21]	None				
Norway [23]	$T \leq 0.27 \cdot h$ (s), h = room height	+	125-4000	T20 according to ISO 3382-2 Max. in each 1/1 octave band. For 125Hz, max. +40% accepted.	Additional criterion for α_m, cf. [23]
Portugal [24]	$A \geq 0.25 \cdot S_{floor}$ (m^2)	–	500-2000	A defined as the average of 500, 1000 and 2000 Hz.	Applicable corridors which are mainly used to access classrooms
Spain [25]	$A \geq 0.2 \cdot V$ (m^2) V= volume	–	500-2000	A defined as the average of 500, 1000 and 2000 Hz.	Only applicable to corridors with doors opened to classrooms or the like.

(1) Overview information only. Detailed requirements and conditions are found in the references.
(2) Rooms unoccupied, unless other conditions indicated.
(3) Requirements for corridors bigger than 250 m^3. Depending on volume each requirement is applied. If rooms are smaller than 250 m^3, then the absorption area must be greater than $0.50 \cdot S_{floor}$

As seen from Tables 3 and 4, Denmark, Norway and France have reverberation time requirements. The rest have equivalent sound absorption area requirements. Concerning the requirements for stairwells and corridors in each country, reverberation time limits in Denmark and Norway are lower (stricter) in corridors than in stairwells, as long as the height is less than 3 m in the case of Norway. England also requires more sound absorption to corridors than to stairwells, while Belgium and France require the same equivalent sound absorption area for stairwells and corridors in schools.

As in section 3, the variety of descriptors complicate comparisons between countries. To allow a comparison, the Figure 2a shows the values of the reverberation time requiered to a corridor and a stairwell whose dimensions are stated in the graphs. The rooms correspond to a real school in Madrid. Figure 2b shows the ratio of the equivalent sound absorption area to floor surface for the same stairwell and corridor. The conversion between descriptors was performed in the same way as described in section 3.





* Method A acc. Approved Document E. Resistance to sound has been applied. The reverberation time and A/S_{floor} were calculated for a minimum α_w of a class D absorber.

Important details about requirements, e.g. frequency ranges can be found in tables 3 and 4.

Fig. 2a: Estimated reverberation time required for an example of a stairwell and a corridor in a school

Fig. 2b: Estimated A/S_{floor} ratio required for an example of a stairwell and a corridor in a school

From the Figures 2a and 2b, it can be said that all countries apply similar requirements as reverberation times limits vary from 0.7 s to 1.3 s, excluding Portugal with the highest reverberation time required. Norway requires a lower reverberation time and also a higher sound absorption area to floor surface ratio: 0.6, whereas the average ratio of A/S_{floor} in this example results in 0.37 for stairwells and 0.43 for corridors.

5 DISCUSSION, CONCLUSIONS AND SUGGESTIONS

Some countries regulate acoustic conditions for stairwells, corridors and other circulation spaces to avoid noise propagating to other adjoining rooms and/or to create more comfortable acoustics. The room acoustic criterion for stairwells and corridors in housing and schools found in the regulations of the selected countries is either reverberation time or equivalent sound absorption area. For the room types dealt with in this paper, a few countries have no acoustic requirements or just for some of the room types.

While reverberation time can be measured in situ and allows in-situ verification of requirements, sound absorption is easier to apply during the design stage of a building. Nordic countries such as Norway and Denmark have reverberation time requirements, whereas the rest have sound absorption requirements. France has also reverberation time requirements for schools.

Apart from the fact that some regulations prescribe reverberation time limits or other sound absorption limits, the following aspects vary, which make comparisons between regulations more complicated:

- Frequency ranges: In general all countries include the frequency range 500-2000 Hz. However, Norway use the extended range to 125-4000 Hz for corridors. That means that even when requirements seem to be close in different countries, the frequency range considered may lead to a very different perception of spaces and different construction solutions, e.g. Norway also have regulations in the lower frequency range.
- In Norway and Denmark, reverberation time must be fulfilled in each octave band, but in France it is the average of 500, 1000 and 2000 Hz.
- Among the countries with sound absorption requirements, England is the only country where sound absorption (Method B, see [15]) must be fulfilled in each octave band from 250 to 4000 Hz. In the rest of the countries, sound absorption area is expressed as a single number.

- When the equivalent sound absorption area is weighted, A in Spain and Portugal is the arithmetic average for 500-2000 Hz in octave bands, but the equivalent sound absorption area A in Belgium and France is weighted from 250 to 4000 Hz according to EN ISO 11654 [10].
- The standard EN ISO 11654 [10] is currently under revision (ISO/WI from 2014), but due to lack of agreement on the weighting procedure, including frequency range, and the role of 125 Hz in the standard, it's unclear if agreement will be obtained.

As with other acoustic requirements, see e.g. [2], [3] and [5], harmonization of descriptors would facilitate exchange of construction solutions and help in discussing and optimizing acoustic criteria. The field cases in sections 3 and 4 were developed to allow for comparison between requirements and lead to the following conclusions:

- In general, requirements are stricter for corridors and stairwells in schools than in housing, and in some countries, like Spain and Portugal, there are not requirements for these spaces in housing.
- For housing, reverberation times spread significantly; there is a variation of 0.9 s between limits. Norway requires a lower reverberation time and thus also a higher sound absorption area to floor surface ratio in the field case: 0.6 for corridors, whereas the average ratio of A/S_{floor} in this field case results in 0.34 for stairwells and 0.39 for corridors.
- For schools: All countries apply similar requirements, excluding Portugal with the highest reverberation time allowed. Norway requires again the lower reverberation time, and thus a higher sound absorption to floor surface ratio which results in 0.6 as well for the field case. The average ratio of A/S_{floor} in this field case results in 0.37 for stairwells and 0.43 for corridors.

Following the results for the acoustic requirements for stairwells and corridors and previous results from comparative studies of other acoustic requirements for housing and schools, see e.g. [1], [3], [5], [6], [7], it is suggested that all countries consider reviewing their national acoustic requirements and revise them, if needed. However, regulations typically apply to new-build only, and since a major part of the building stock in Europe – and probably also outside Europe – has been constructed before there were acoustic regulations, it should be considered to include acoustic requirements or recommendations for renovation purposes and create awareness about the benefits for occupants in housing and students in educational buildings. Some countries also have national acoustic classification schemes, and the idea of having more acoustic quality levels could be useful, although most of the existing classification schemes don't have quality classes fitting the lower acoustic quality for old buildings, and – considering the topic of this paper – many of them don't include stairwells and corridors. For an overview of main characteristics for national acoustic classification schemes in Europe, see [28], but in-depth information about room types included is not a part of [28].

Finally, based on the experience of finding acoustic limit values from various countries, it should be emphasized that the whole structure of building codes and related documents is important in practice to get full information, awareness and access to the relevant acoustic regulations – and other building regulations. In many countries, it is very difficult to get a complete overview of acoustic regulations, guidelines and recommendations due to a complex variety of documents published by authorities, institutes, councils, standardization organizations and various other organizations, and most often there is no joint document linking those documents together. However, that was actually made in France in 2017, cf. [17] with a guide to the French acoustic regulations for buildings. The same is needed in many other countries – or even better to do as e.g. Norway did, see [23], to include all acoustic limits for all buildings in the same document, which is referred to in the building regulations. Thus, it could be suggested all countries to consider the structure of regulations and related documents and optimize for easier access and awareness.

Acknowledgements

The authors are grateful to Lieven De Geetere, Catherine Guigou Carter, Jorge Patrício, and Simone Secchi, who assisted by answering questions about national acoustic regulations. However, the authors are solely responsible for errors in the paper, and any comments, corrections and updated information will be appreciated.

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